First steps of numerical simulation using Artificial Intelligence

Vincent Vadez, François Brunetti, Pierre Alliez

First Steps of Numerical Simulation using Artificial Intelligence

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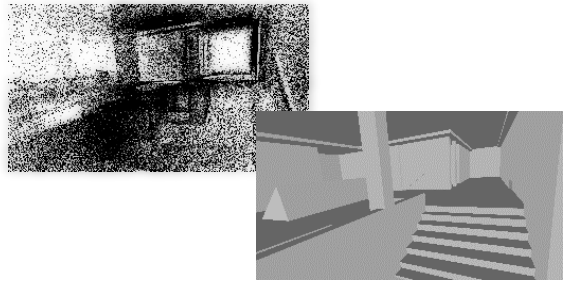
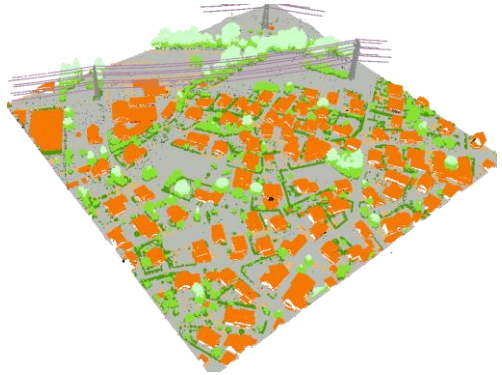
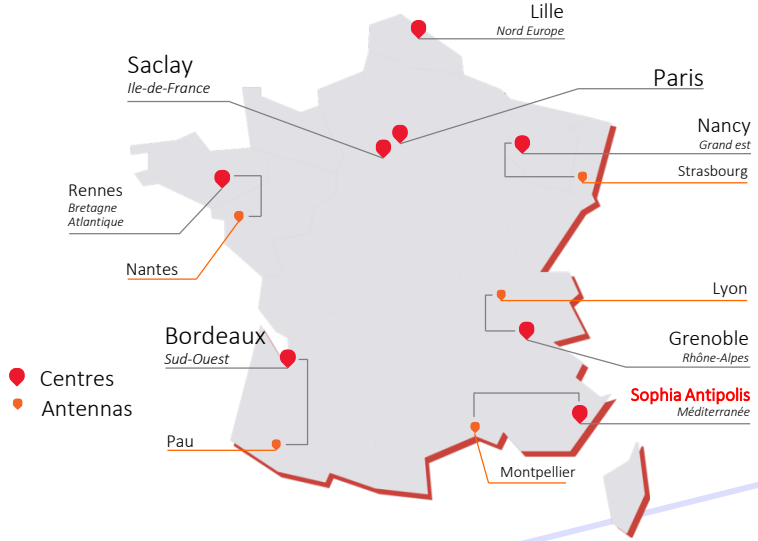
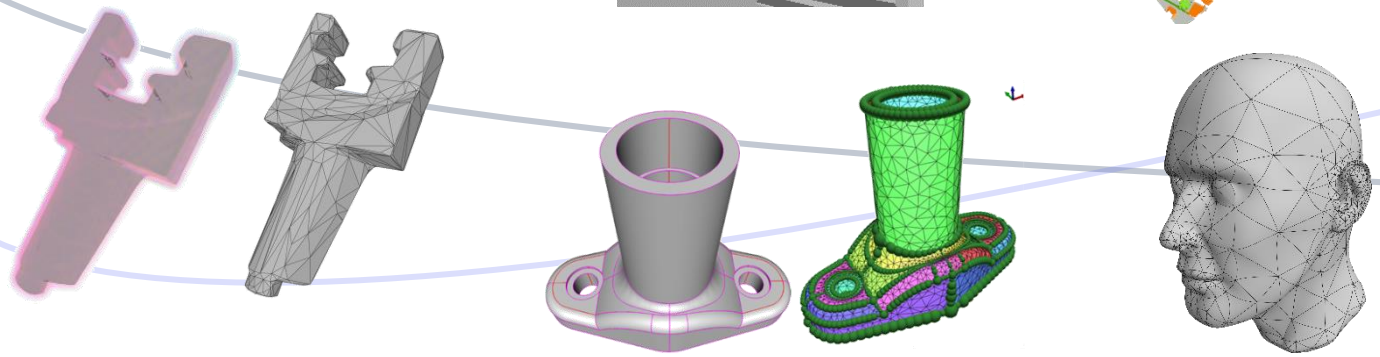
Project-Team *Titane*

- **Geometric modeling of 3D scenes from measurement data**
  - Analysis, reconstruction, approximation
  - Computational geometry, geometry processing, machine learning









CONTEXT AND MOTIVATIONS

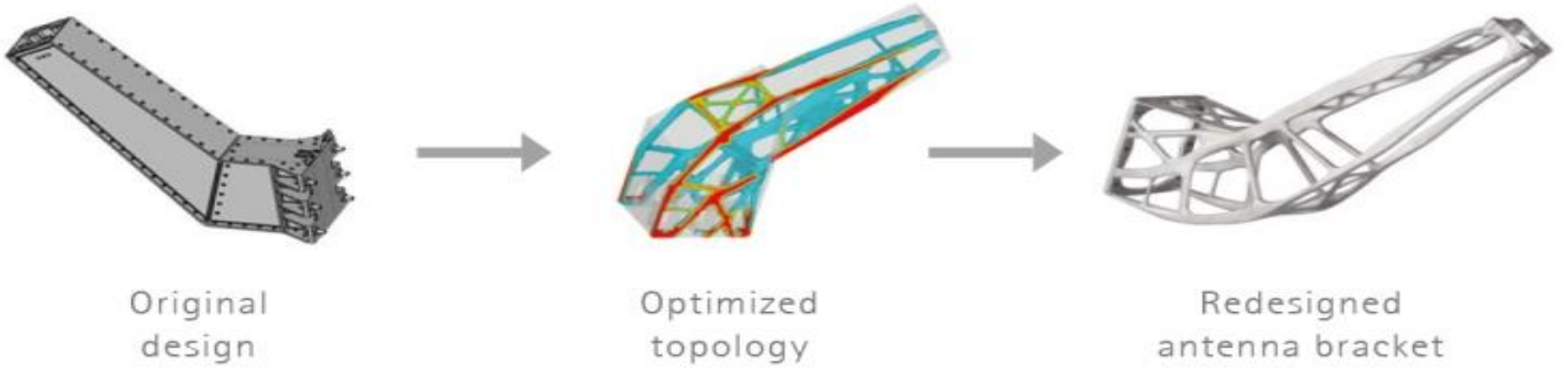


Image from www.eos.info

- **Additive manufacturing yields increasingly complex objects**
  - Reduced weight via topology optimization
  - Many more facets elements are required to describe these free-form shapes, which are later added to the full satellite model.

CONTEXT AND MOTIVATIONS

- **Context of real-time simulation & sensibility**
  - Radiative thermal simulation is time-consuming: $O(n^2)$ complexity for the view factors, with ***n*** the number of faces of the mesh.
  - Full simulation intractable on the complete satellite model, in a reasonable time.
  - A thermal-aware geometric approximation process is required, allowing real-time simulation and beyond (multi-physics simulation and predictions).

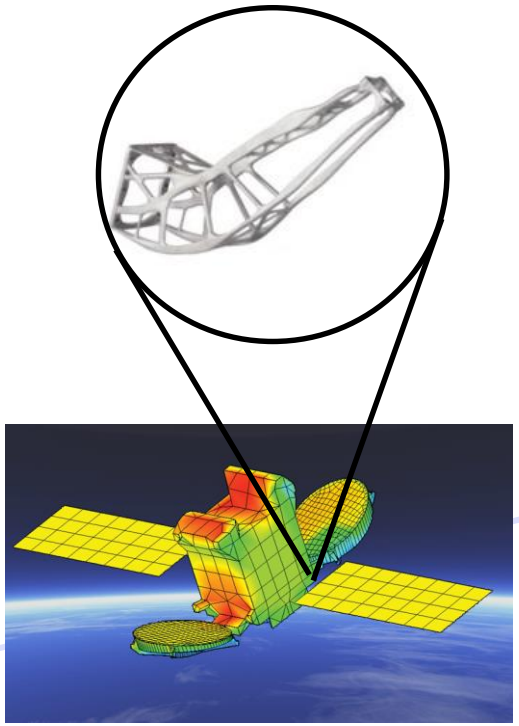
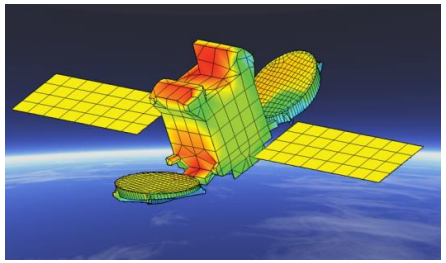


Image from www.ata-e.com

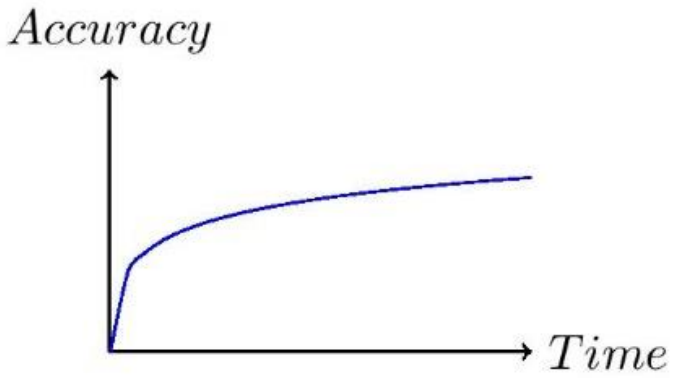
PROBLEM STATEMENT

- **Input:** Complex surface mesh (many facets and occlusions, created by a CAD software)

- **Output:** Approximated model respecting the view factors of the thermal nodes



- **Guarantees:** Error bounds under wide range of configurations and conditions
- **Goal:** Optimize trade-off between accuracy and time



DIRECTIONS

- **Topic of Ph.D. thesis:** Design a geometric approximation method preserving a *simulation-aware* error metric rather than a *geometric* error metric.

- **Application to space thermal analysis:** view factor computation and model reduction

- **Goals:**
  - Compute reference view factors
  - Compare with approximated view factors
  - Evaluate simulation with approximation
  - Utilize supervised machine learning to automate the reduction process, leveraging a large training dataset.

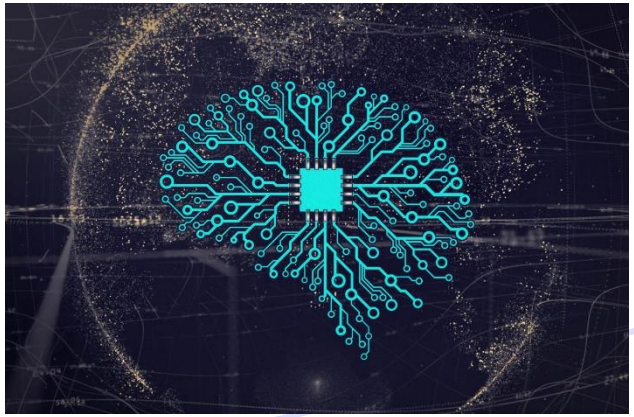
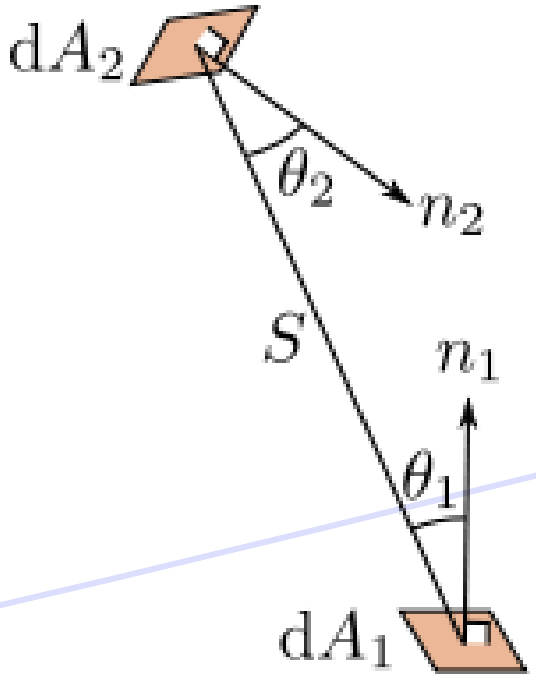


Image from www.warontherocks.com

VIEW FACTOR

$$F_{1\to 2} = \frac{1}{A_1}\int_{A_1}\int_{A_2}\frac{\cos\theta_1\cos\theta_2}{\pi s^2}\,\mathrm{d}A_2\,\mathrm{d}A_1$$

$$dF_{1\to 2} = \frac{\cos\theta_1\cos\theta_2}{\pi s^2}\mathrm{d}A_2$$



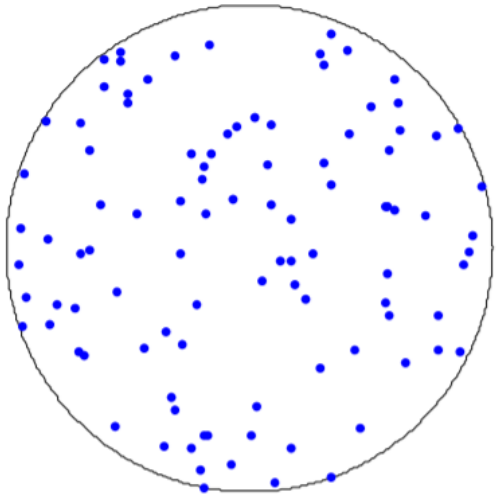
View factors depend on 3 components:

- area of the faces
- distance between them
- orientation

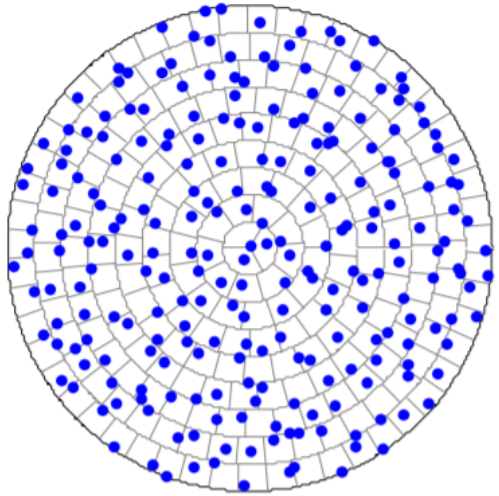
RELATED WORK

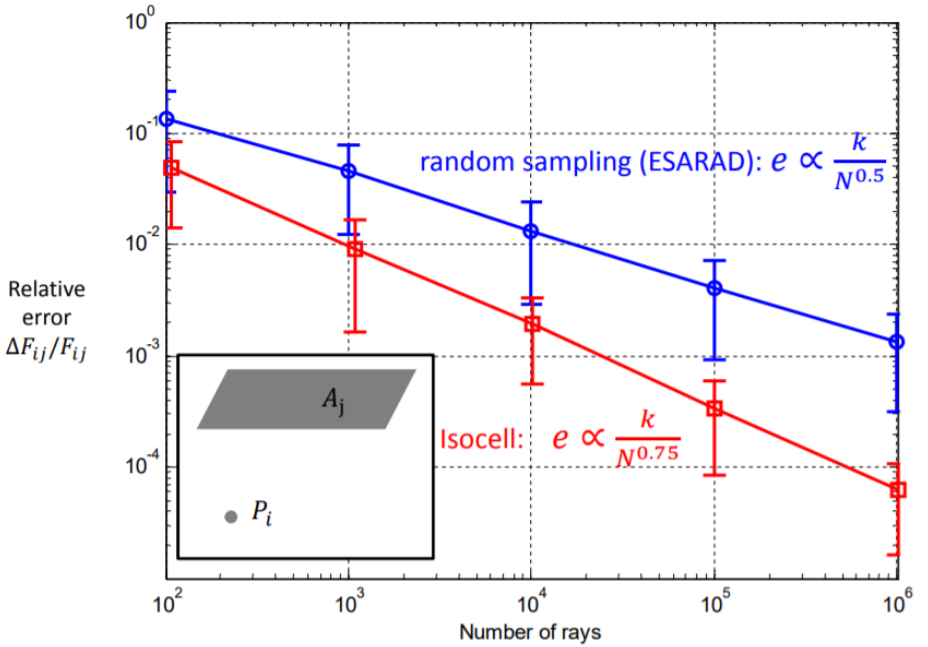
- **Accelerating computation of view factors**
  - **Jacques, Masset, Kerschen**: *Ray tracing enhancement for space thermal analysis: isocell method* , 27th Space Thermal Analysis Workshop, ESTEC.

Random (classic) sampling



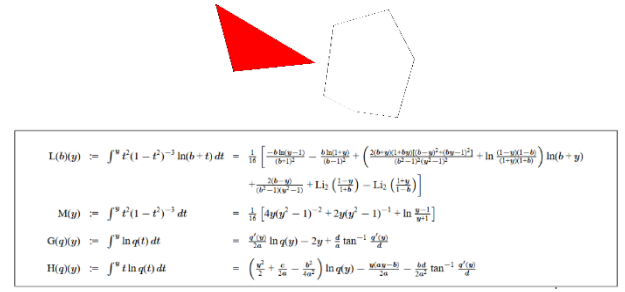
Isocell sampling





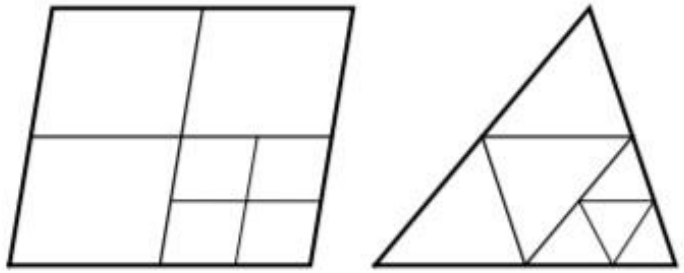
RELATED WORK

- **Schröder, Hanrahan**: *On the Form Factor between Two Polygons.* Proceedings of ACM SIGGRAPH 1993.
  → Closed form solution for the view factor between two convex polygons

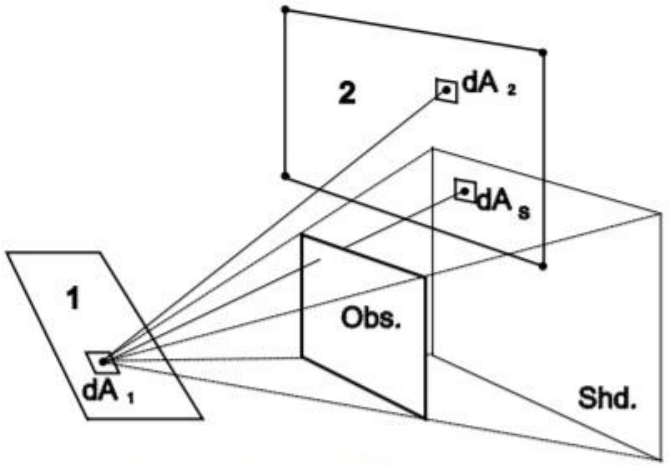


Closed form
(without obstruction)

- **Walton**: *Calculation of Obstructed View Factors by Adaptive Integration.* NIST Report, 2002.



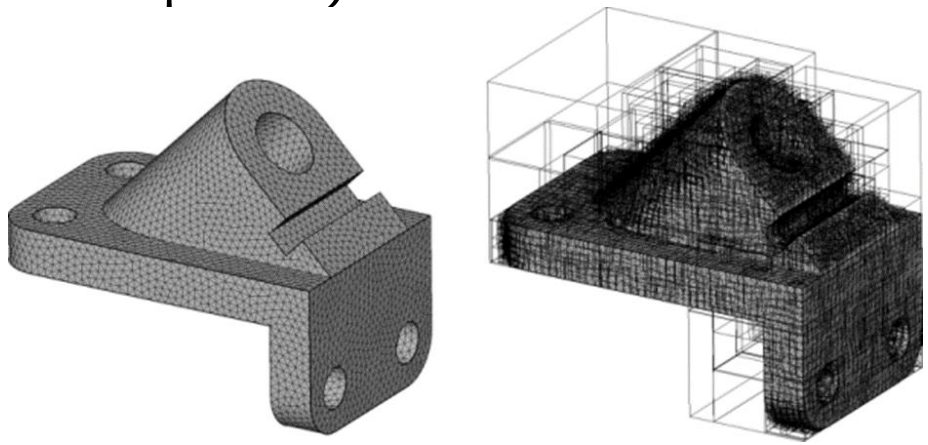
Adaptive Division of Polygons



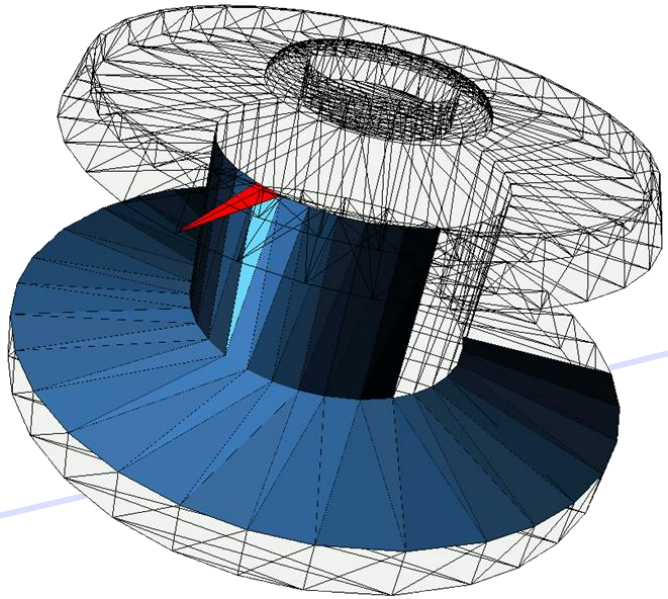
Partially Obstructed View

ACHIEVEMENTS

- **Hierarchical geometric data structure:** AABB-tree (fast intersection queries)

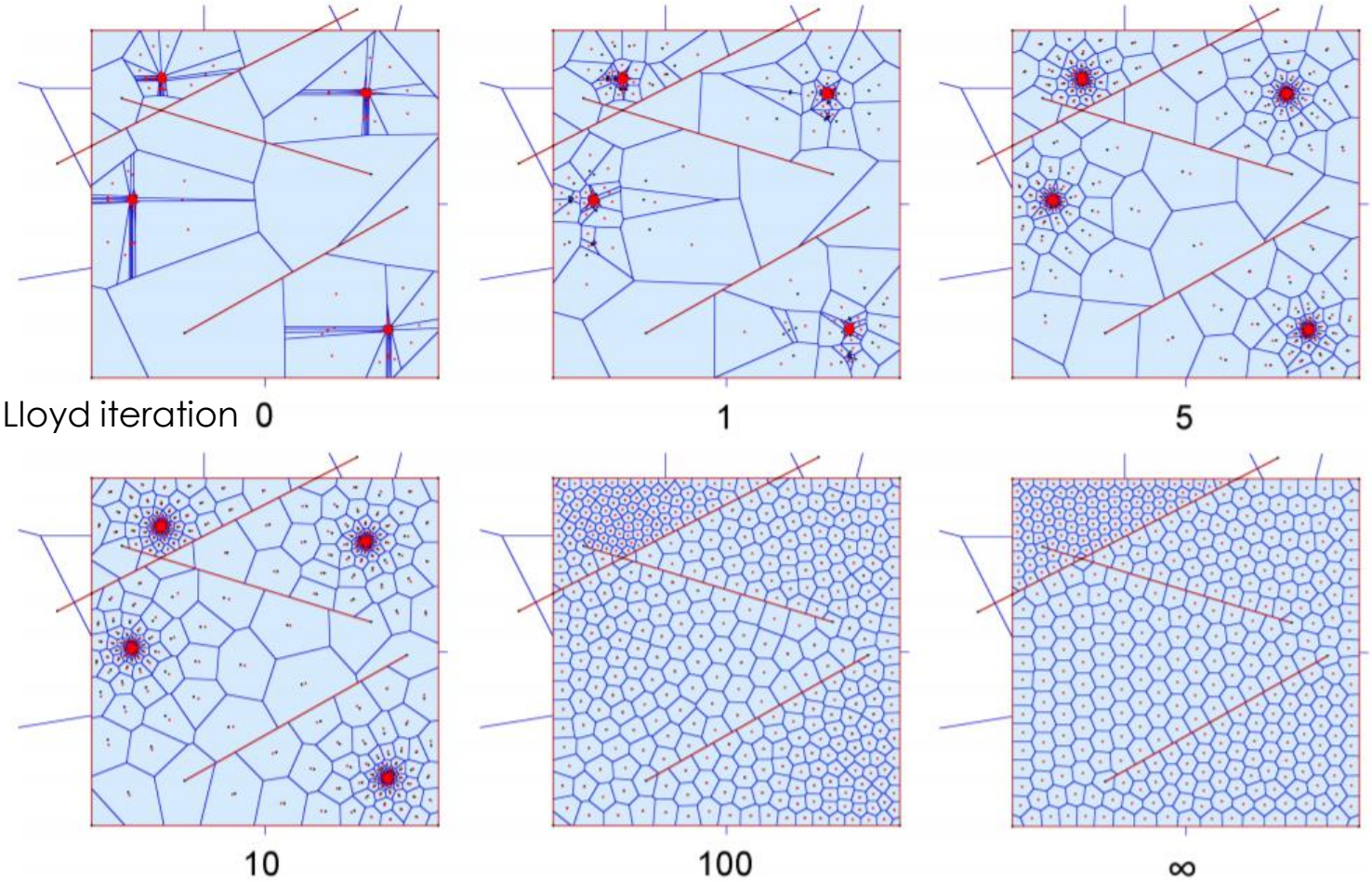


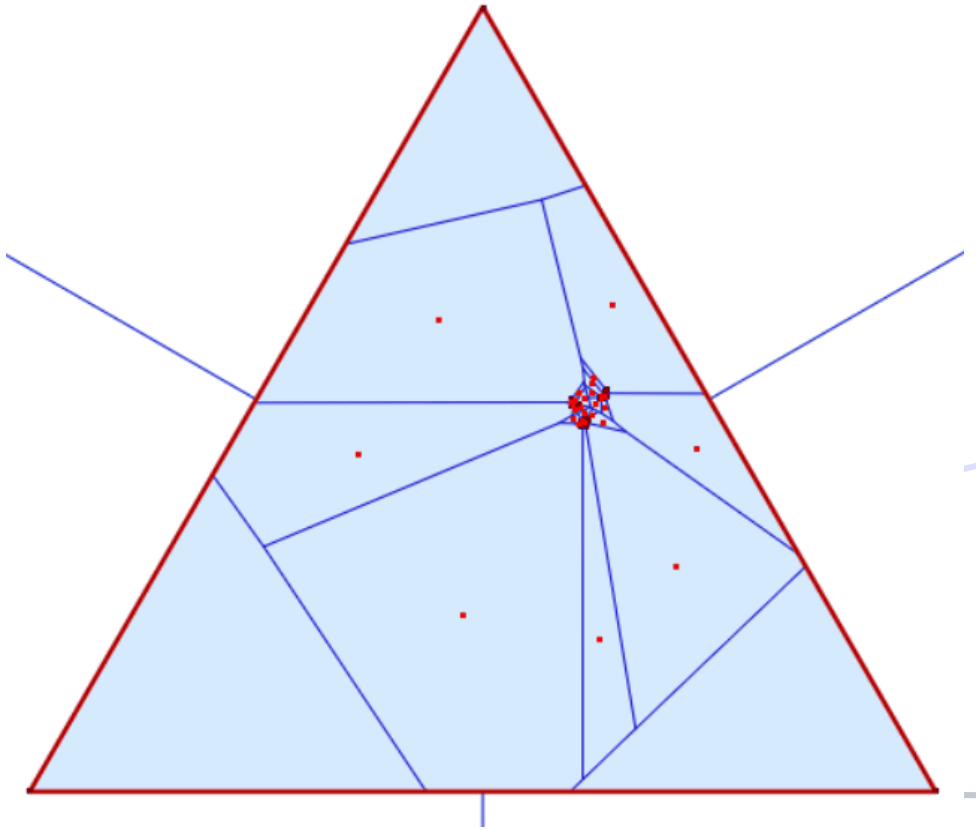
- **Closed form solution** when full visibility (**Schröder**)
- **Quadrature in the presence of occlusions:**
  - Point-based (via bounded centroidal Voronoi diagrams)
  - Triangle-based (recursive longest bisection)



Reference view factors

Bounded Centroidal Voronoi Diagrams (CVD)

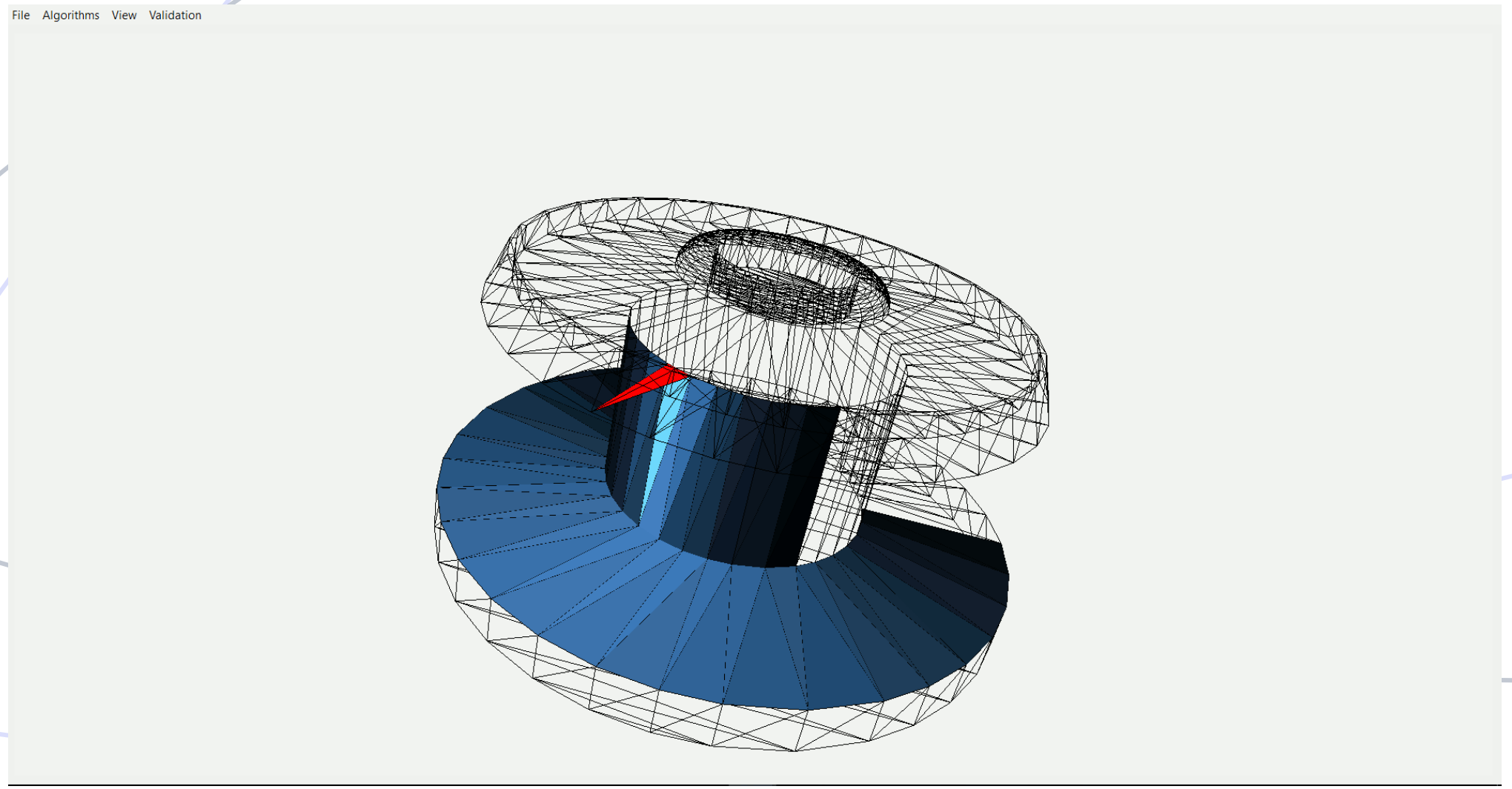




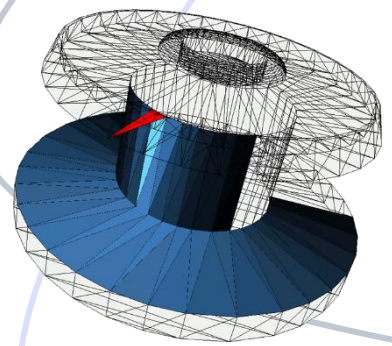
Lloyd iterations

Tournois, Alliez, Devillers: *2D Centroidal Voronoi Tessellations with Constraints.*

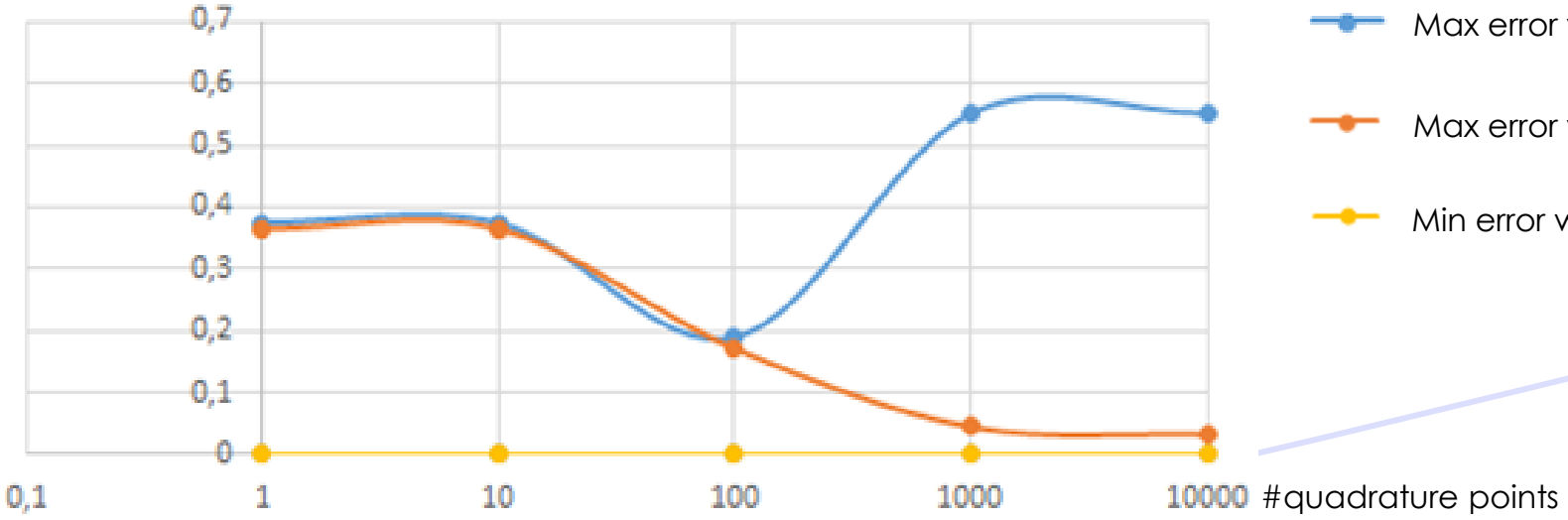
VIEW FACTORS (VF)



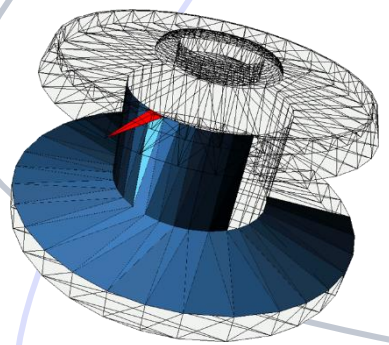
COMPARISONS



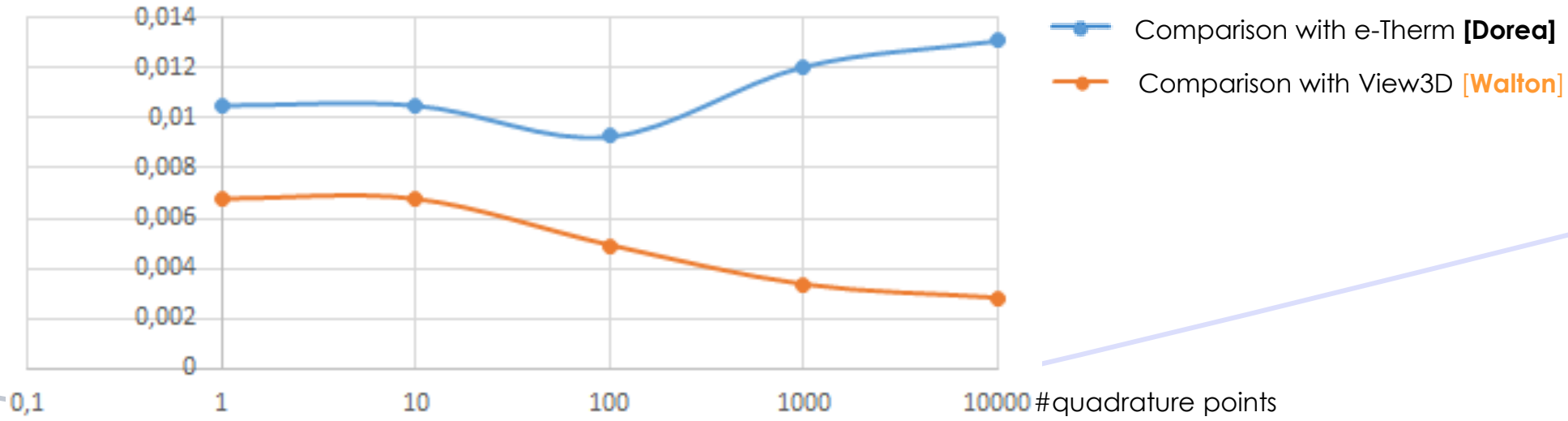
Maximum difference of view factors



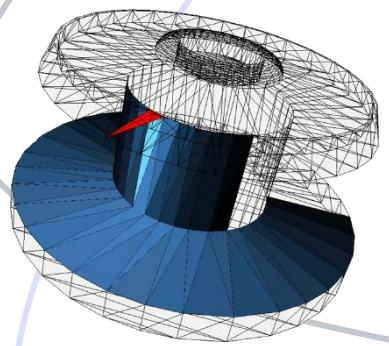
COMPARISONS



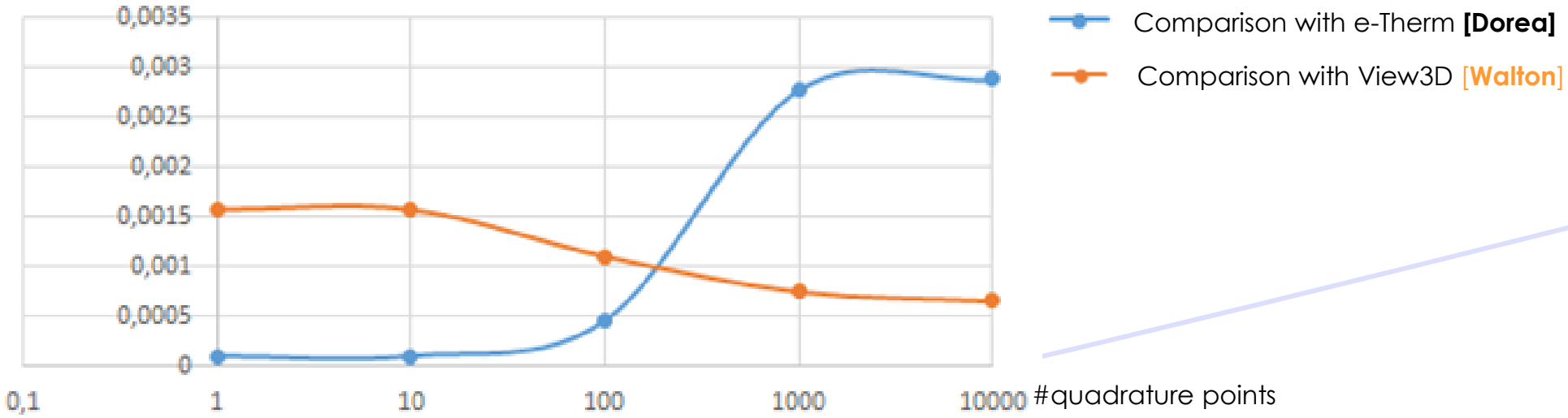
Standard deviation of view factor



COMPARISONS

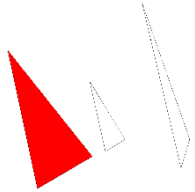


Average error of view factor

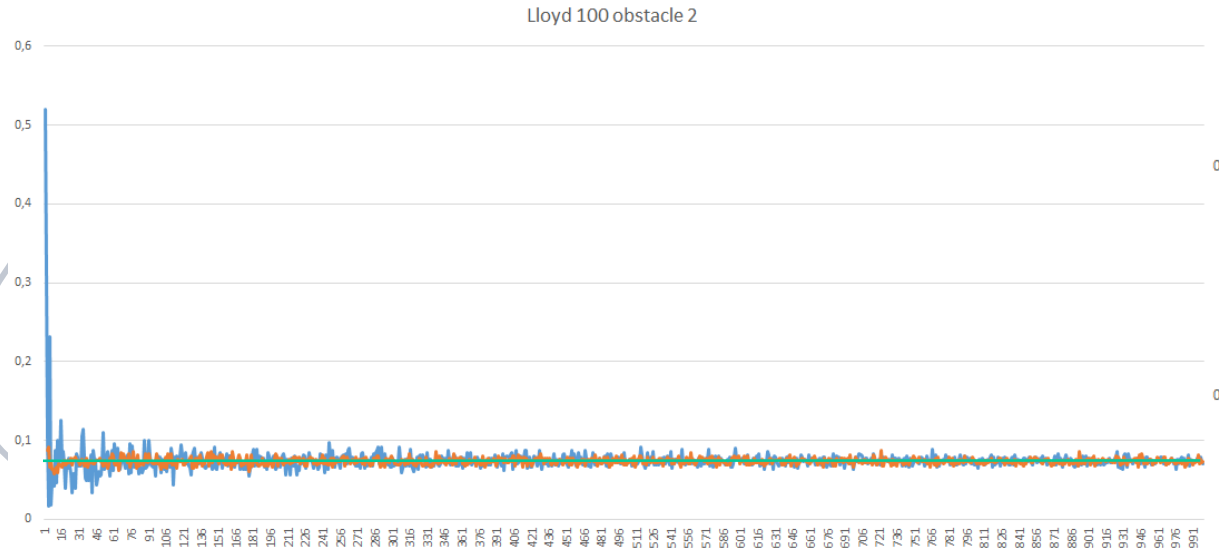


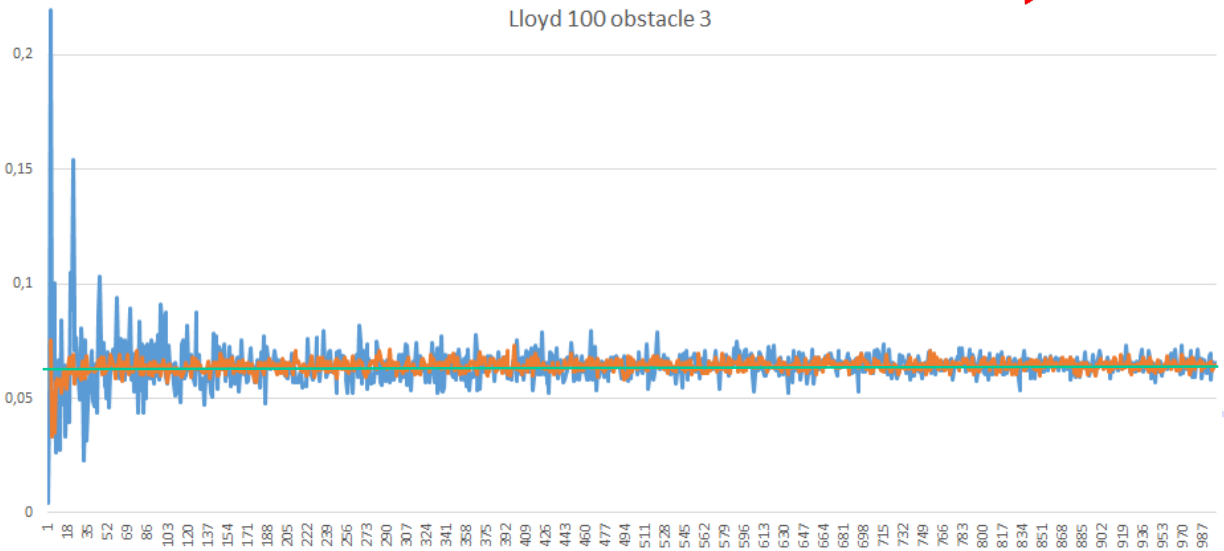
RANDOM SAMPLING VS CVD

Results with two random triangles configuration and an obstacle between them

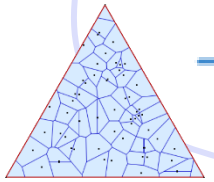


View factor value

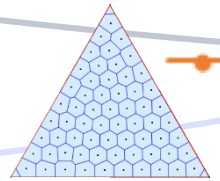




#quadrature points



Random uniform sampling

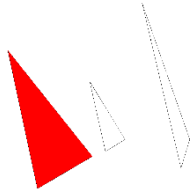


Bounded Centroidal Voronoi

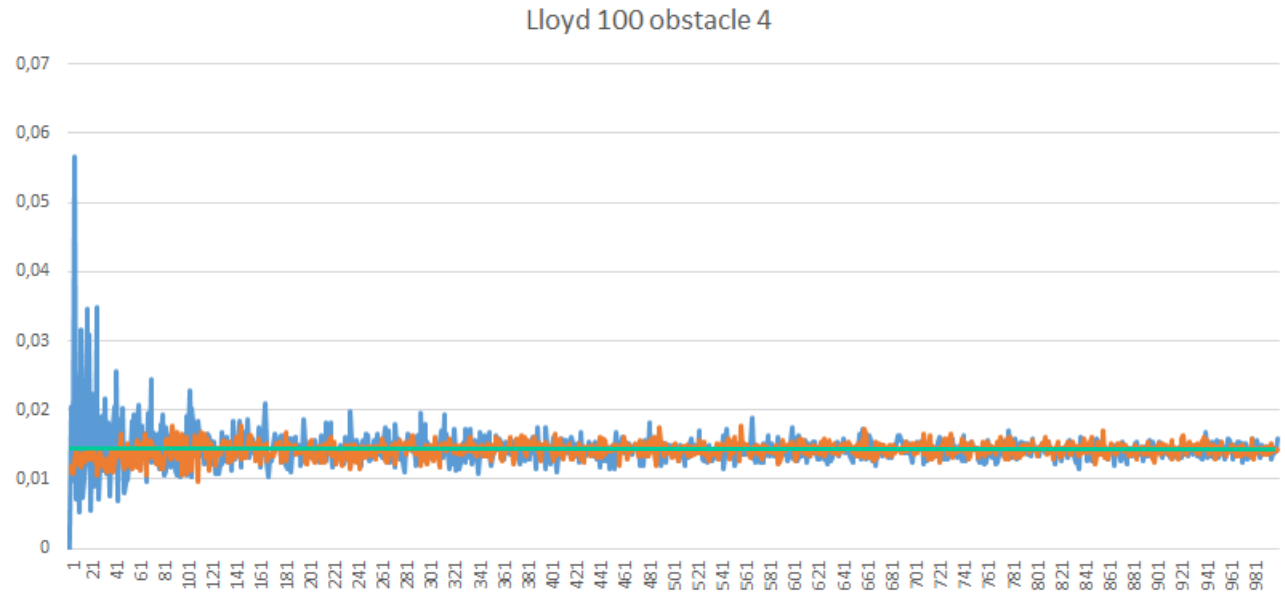
View factor exact value

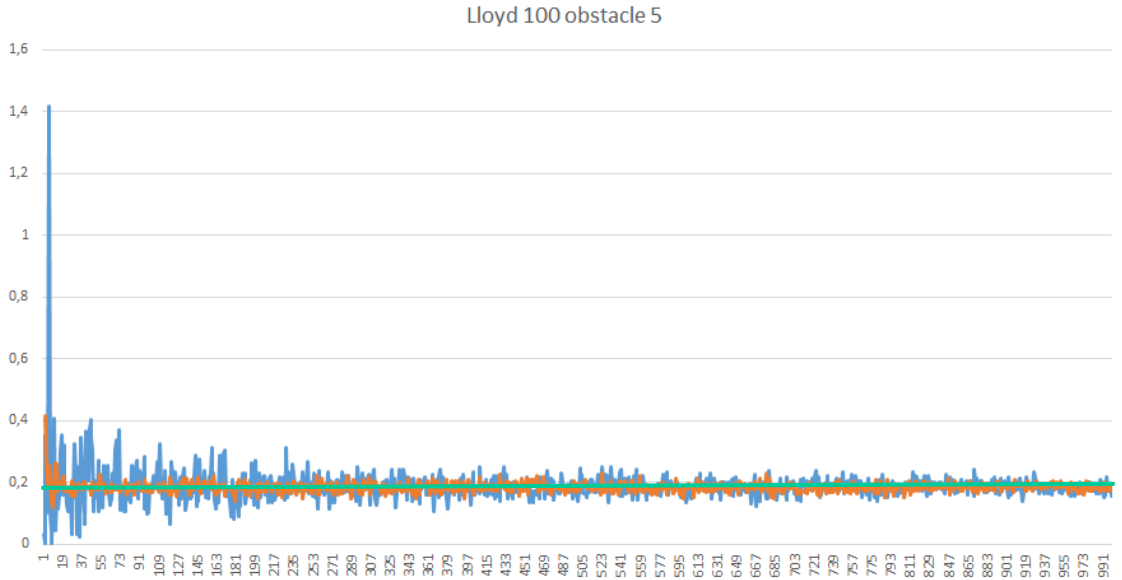
RANDOM SAMPLING VS CVD

Results with two random triangles configuration and an obstacle between them

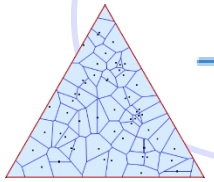


View factor value

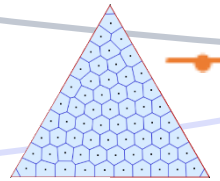




#quadrature points



Random uniform sampling



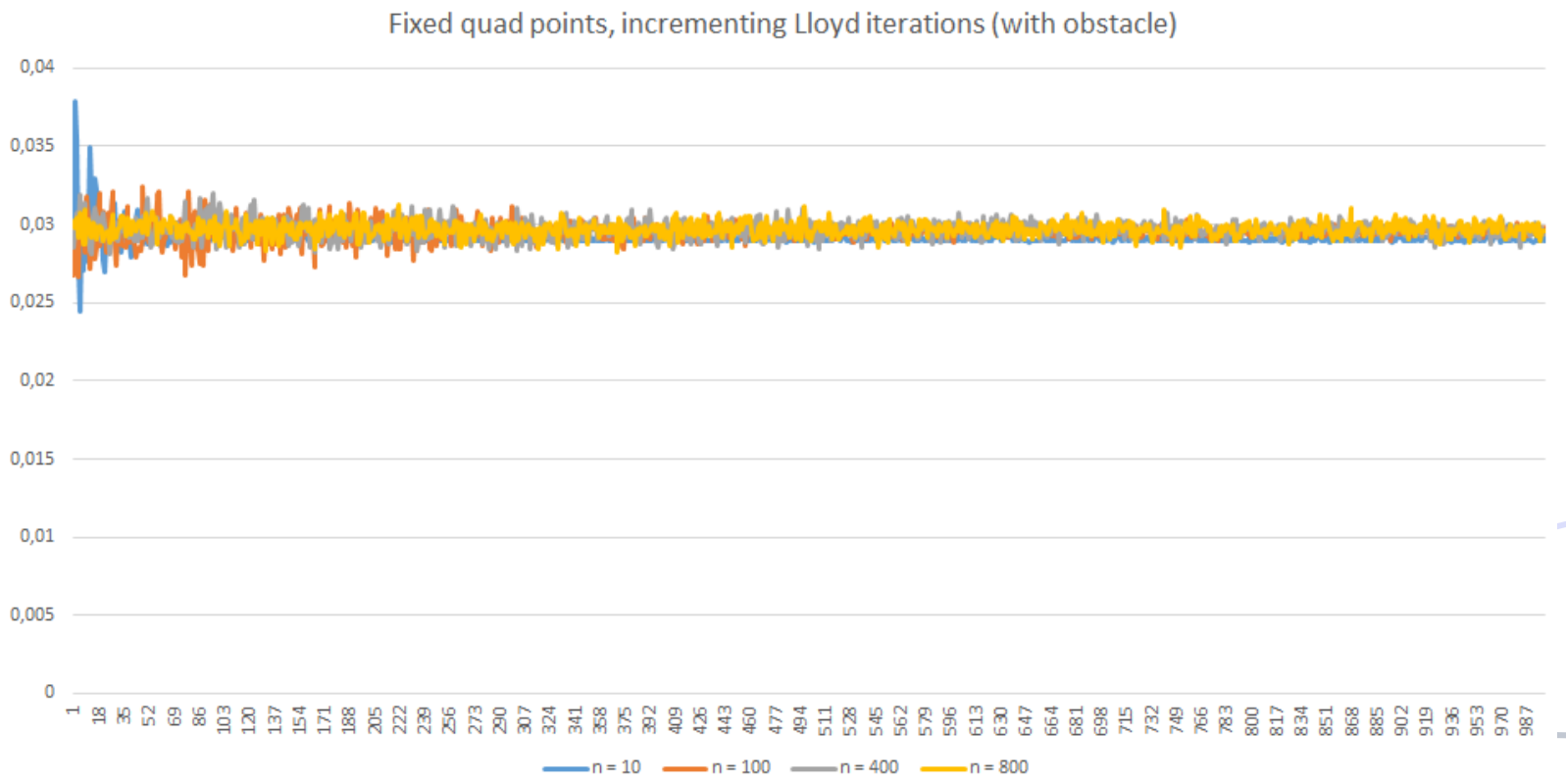
Bounded Centroidal Voronoi

View factor exact value

VARYING #LLOYD ITERATIONS

Results with two random triangles configuration and an obstacle between them

View factor value

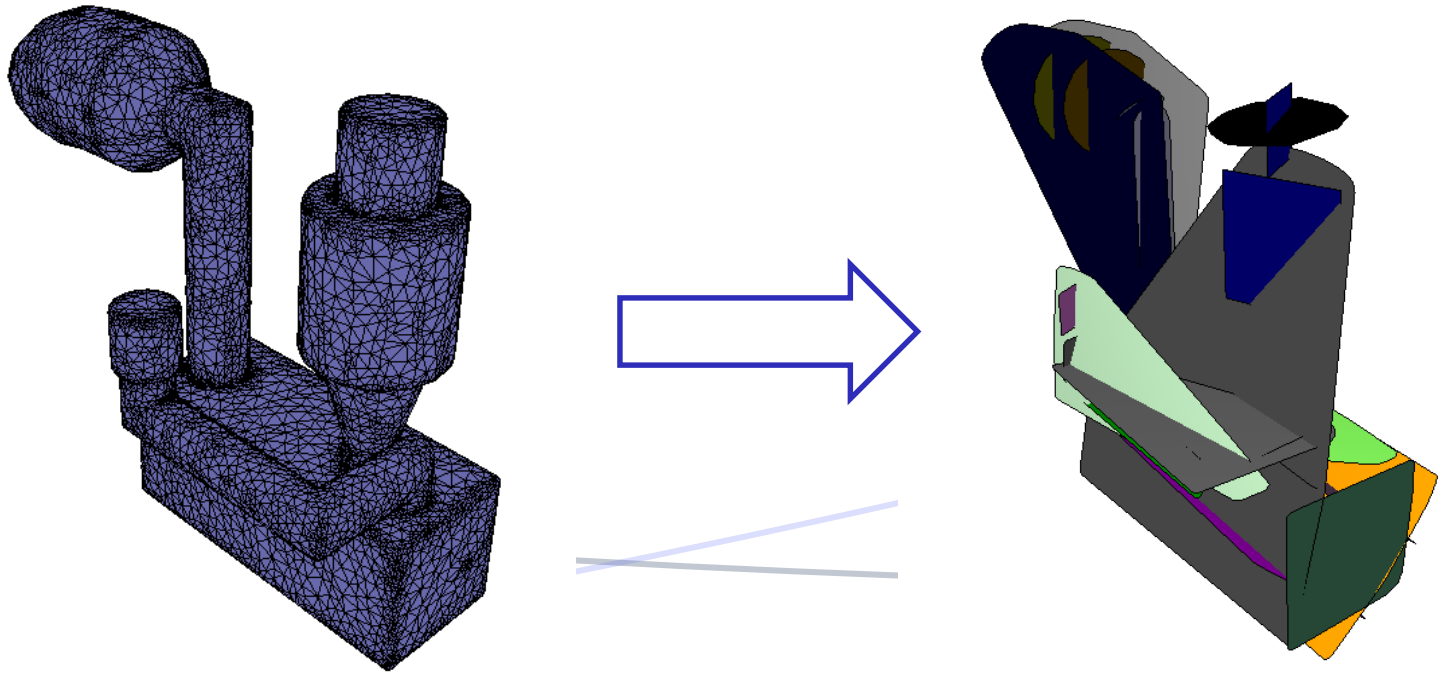


#Lloyd iterations

ON-GOING WORK

	1	2	3	4	5	6	7	8
1	11	12	0	0	0	0	0	0
2	0	22	0	0	0	0	0	0
3	31	32	33	0	0	0	0	0
4	41	42	43	44	0	0	0	0
5	0	0	0	0	55	56	0	0
6	0	0	0	0	0	66	67	0
7	0	0	0	0	0	0	77	78
8	0	0	0	0	0	0	87	88

Approximation method guided by preservation of the view factors. We keep the constraint of the thermal nodes in order to compare the matrices of the radiative surfaces per nodes.



ON-GOING WORK

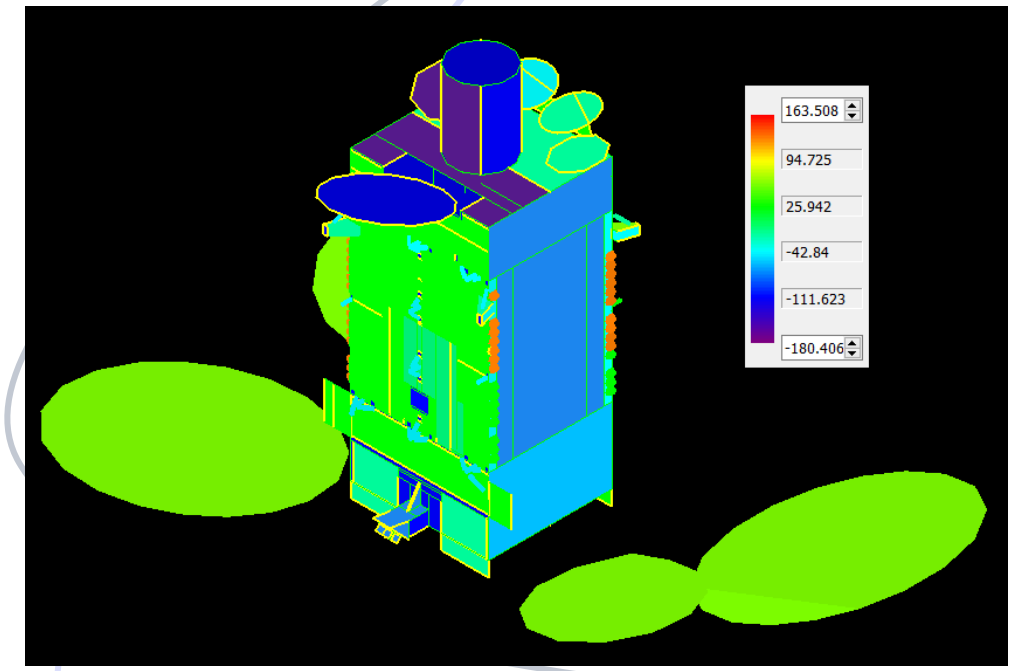


Illustration of the thermal nodes with e-Therm

- **Simplification** via face clustering in order to best approximate the thermal nodes.
- **Comparison with the reference calculation thanks to thermal nodes:**
  - Main idea: compare the radiative surfaces by node matrices from the reference calculation case and the approximation one

WHAT'S NEXT: SUPERVISED MACHINE LEARNING

- **Goal**: learn geometric error metric able to govern an automatic approximation algorithm so that the resulting thermal simulation is as accurate as possible to a reference calculation.
- Constraints = thermal nodes, so we can compare the radiative surfaces of each node before and after approximation.

[Jacobson] Thingie10K (training dataset)

THANK YOU

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